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Quality Assurance of Concrete Structure in Construction Process by Measuring Curing Effect by Using Odor Sensor

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***ABSTRACT*:** In order to assure the quality of concrete structure in construction process, the odor strength measured by using odor sensor was used to evaluate curing effect. Then, the compressive strength, temperature and humidity and odor strength in ordinary concrete N and portland blast-furnace slag cement concrete BB were shown in water curing (=standard curing), indoor and outdoor atmospheric curing condition. The odor strength in the concrete N and BB was related to the change in the temperature and humidity which greatly influenced on the curing effect. The difference between odor strength in the standard curing and that in each curing condition was defined as the difference in the odor strength. And the difference in odor strength in slag powder concrete BP cured in water curing (=standard curing) for different period before exposing in outdoor atmosphere in winter season were evaluated at the age of 14 days. A necessity to prolong the moisture curing for the slag powder concrete BP compared with the ordinary concrete N to obtain a required curing effect was shown by measuring the odor strength and long term compressive strength.

KEYWORDS: Odor strength, Compressive strength

1. INTRODUCTION

The effective utilization of blast-furnace slag powder for replacement cement materials is very important from the view point of saving resources. However, the initial moisture curing period for the blast-furnace slag concrete has to prolong because the compressive strength development of the slag concrete is slower than that of ordinary concrete. It is important for the slag concrete to develop simple method of evaluation of curing effect, since drying and low-temperature environment in the early ages lowered the compressive strength and durability of the concrete in comparison with standard curing [1], [2].

In this study, the relation between concentration of calcium hydroxide solution and odor strength was examined since the amount of crystallization of calcium hydroxide increases with progress of hydration reaction of the cement in concrete by curing [3]. Then the relation between temperature and humidity and odor strength in the specimen of ordinary concrete N and B type portland blast-furnace slag cement concrete BB were examined in water (standard curing), indoor and outdoor atmospheric curing condition. Finally, the odor strength in concrete specimen of slag powder concrete BP cured in moisture curing condition (standard curing) for different period before exposing in outdoor atmosphere in winter season were measured at the age of 14 days. The difference between odor strength in the standard curing and that in outdoor curing condition was defined as the

Table 2.1 Mixture proportions of concrete

Type	W/B (%)	s/a (%)	Slump (cm)	Air content (%)	Unit content (kg/m^3) W*	C*	BFP*	S*	G*	AE*
N	60.0	44.6	8.0	6.0	175	292	-	771	1000	0.18
BB					170	283	-	776	1006	0.17
BP			12.0	5.5	175	146	146	766	994	0.18

*W, C, BFP, S, G and AE show the unit content of water, cement (normal portland cement N and B type portland blast-furnace slag cement), blast-furnace slag powder, fine aggregate, coase aggregate and air-entraining agent.

difference in odor strength, and the relations between the difference and the length of moisture curing (standard curing) period and compressive strength at the age of 180 days were examined for slag powder concrete BP compared with ordinary concrete N.

2. EXPERIMENTAL OUTLINE

2.1 Materials and mixture proportions

Normal Portland cement (density: 3.16g/cm^3), B type portland blast-furnace slag cement (density: 3.04g/cm^3), blast-furnace slag powder (density: 2.91g/cm^3 and specific surface area: 6050cm^2/g), and chemical admixture such as air-entraining agent AE (principal components: natural resinate) were used in the concrete mixtures. Natural mixed sand S as a fine aggregate (density in saturated surface-dry condition: 2.57g/cm^3; absorption: 3.16% and fineness modulus: 2.73) and crushed stone G as a coarse aggregate (maximum size: 20mm; density in saturated surface-dry condition: 2.68g/cm^3 and absorption: 1.34%) were used. Table 2.1 shows the mixture proportions of ordinary concrete: N, B type portland blast-furnace slag cement concrete: BB, and slag powder concrete (50% of normal portland cement replaced with blast-furnace slag powder): BP. Water binder ratio was 60%.

2.2 Production of test specimens

A paddle mixer with 50 liters capacity was used with a mixing time of 90 seconds after putting crushed stone, natural mixed sand, cement, water and chemical admixture in order into the mixer. After mixing, slump and air content were measured in accordance with JIS A 1101 and JIS A 1128. A steel form of 100mm diameter and 200mm depth was used for testing compressive strength, and 3 kinds of forms of 75, 100 and 150mm diameter with 150mm depth for measuring temperature, humidity and odor strength in concrete. The required amount of concrete sample to fill half of the form volume was put into the form, and it was consolidated by inner vibrator. Then the remaining half of the form volume concrete was placed and consolidated by the same way. The form was removed after 24 hours.

2.3 Curing condition of specimens

Concrete N and BB shown in Table 2.1 were cured in water bath (in standard curing at 20℃), indoor atmosphere (in the laboratory at 19.1±1℃ and 43±10%R.H.), and outdoor atmosphere (in the outdoor atmosphere sheltered from the rain at 7±5℃ and 68±27% R.H.) for 0.5, 1, 3, 7, 14, 28 and 91 days to measure compressive strength, temperature and humidity and odor strength of test specimen. The period of the outdoor atmospheric curing was 2006/11/30 to 2007/2/28 in case of ordinary concrete N and 2006/12/19 to 2007/3/19 in case of portland blast-furnace slag cement concrete BB.

Concrete N and BP shown in Table 2.1 were cured in water bath (in standard curing at 20℃) for 7 to 14 days. After that outdoor atmospheric curing was carried out outdoors sheltered from the rain at -5.1 to 13.3℃ and 37 to 97% humidity, and the specimen just after removing form was also set outdoors. The period of the outdoor atmospheric curing was 2008/12/9 to 2009/1/6. The outdoor curing was started at the same time to keep the constant influence of fluctuation of outdoor atmospheric temperature and humidity, after each specimen has finished standard curing for a required period. The odor strength in outdoor atmospheric curing was measured at the age of 14 days. All specimens were covered with the hard plastic sheet on the top surface to prevent evaporation for one day and they were set in indoor atmosphere without the influence of harmful effects.

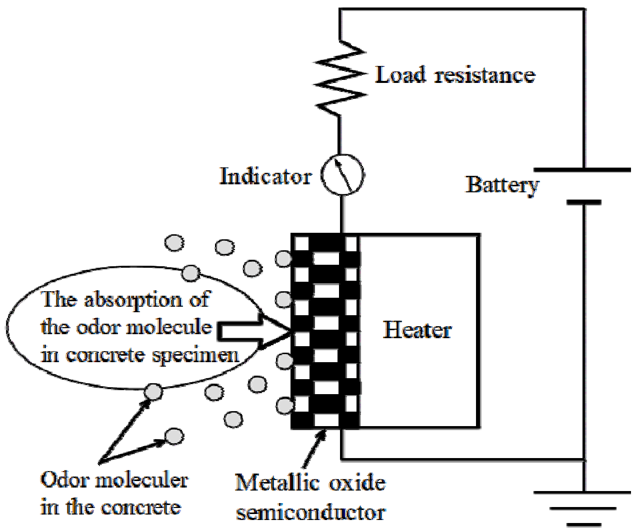

Figure 2.1 Outline map inside the odor sensor

Table 2.2 Variation of the aerial odor strength in the measurement environment

	MIN-MAX	Average	Standard deviation	Coefficient of variation (%)
Indoor	683-949	817	86	10.5
Outdoor	647-822	741	57	7.7

2.4 Measurement of temperature and humidity in concrete specimen and compressive strength test

The temperature and humidity in concrete specimen with 75, 100 and 150mm diameter, and 150mm depth were measured at some ages for each curing condition. A plastic sleeve was buried to insert the temperature and humidity conversion probe at a depth of 70mm on the center of top surface of specimen just after placing concrete. At the age of measuring, the temperature and humidity conversion probe was inserted in the sleeve and the temperature and humidity in concrete specimen were measured in each curing condition. Compressive strength was measured in accordance with JIS A 1108 at the same age as that of measuring the temperature and humidity.

2.5 Measurement of odor strength

Figure 2.1 shows the outline map inside the odor sensor. The instrument equipped odor sensor which consists of two types of highly sensitive metallic oxide semiconductors was used in this study. One semiconductor is sensitive to the odor molecule with relatively high molecular weight and another one is to that with relatively low molecular weight. When the reduction of oxidation reaction of the metallic oxide is caused by the absorption of the odor molecule, internal electrical resistance value of the semiconductor is changed. The change of resistance is converted to a numerical value as odor strength.

In order to introduce the absorption pipe of the instrument into the concrete specimen, a drilled hole with 6mm diameter was made on the center of top surface of concrete specimen at a depth of 70mm for some ages in each curing condition. After removing the bored powder, the odor strength in concrete specimen was measured. As the odor strength is largely affected by aerial odor strength in the measurement environment, it was subtracted from the odor strength measured in concrete specimen. The value was defined as the odor strength in concrete specimen. Then, the sensitiveness of the odor sensor was improved by washing the highly sensitive metallic oxide semiconductor by using the standard air in every measurement condition. Table

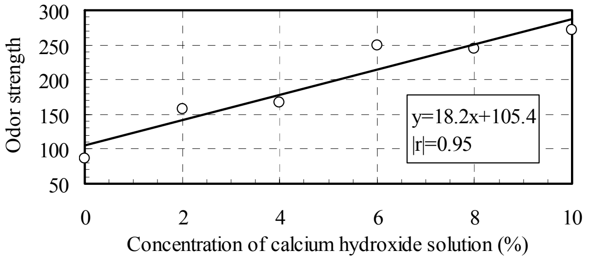

Figure 2.2 Relationship between concentration of calcium hydroxide solution and odor strength

2.2 shows the variation of the aerial odor strength in the measurement environment.

Figure 2.2 shows the relationship between concentration of calcium hydroxide solution and odor strength. The calcium hydroxide was hard to dissolve in water, but some high level concentration of calcium hydroxide solutions were positively used to clarify the relationship. The aerial odor strength in the measurement environment was subtracted from the tested odor strength. The figure shows clear increasing trend of odor strength with an increase in the concentration of calcium hydroxide solution. It therefore was judged that the measurement of the odor strength in the concrete could evaluate the difference of the amount of the crystallized calcium hydroxide formed by the difference of the progression of hydration reaction due to different curing condition.

3. RESULTS AND DISCUSSION

3.1 Strength gain, and temperature and humidity change of concrete specimen with age for each curing condition

Figure 3.1 shows the compressive strength development of portland blast-furnace slag cement concrete in case of each curing condition. The ranges of atmospheric temperature and humidity measured in the condition were shown in this figure. The compressive strength development after the age of

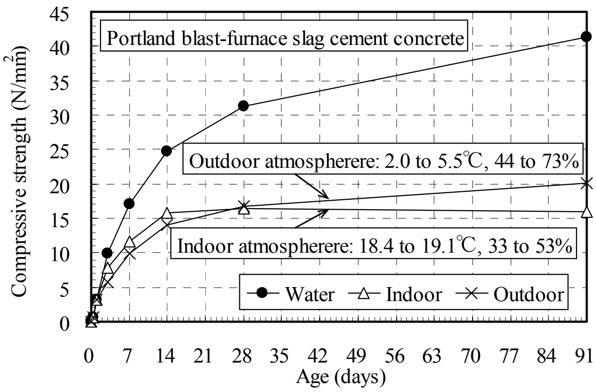

Figure 3.1 Compressive strength development of portland blast-furnace slag cement concrete for each curing condition

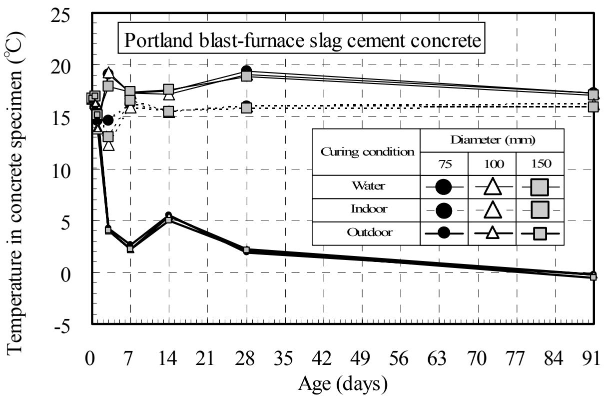

Figure 3.2 Temperature in portland blast-furnace slag cement concrete specimen for each curing condition versus ages

14 days cannot be observed in the indoor atmospheric curing condition because of the evaporation of the water from the specimen due to low atmospheric humidity. However, the slow strength development can be observed after the age of 14 days in the outdoor atmospheric curing condition at which the humidity is higher and the temperature is lower than the indoor atmospheric curing condition. The difference of this compressive strength development shows that structural concrete needs humidity to facilitate required the hardening of concrete.

Figure 3.2 shows the fluctuation of temperature with ages in portland blast-furnace slag cement concrete specimen for each curing condition. Figure 3.3 shows that of humidity with ages in these

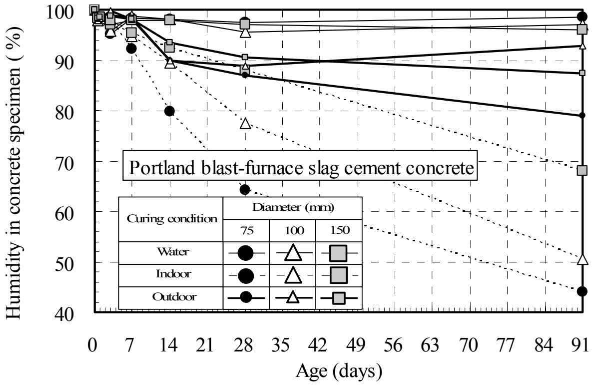

Figure 3.3 Humidity in portland blast-furnace slag cement concrete specimen for each curing condition versus ages

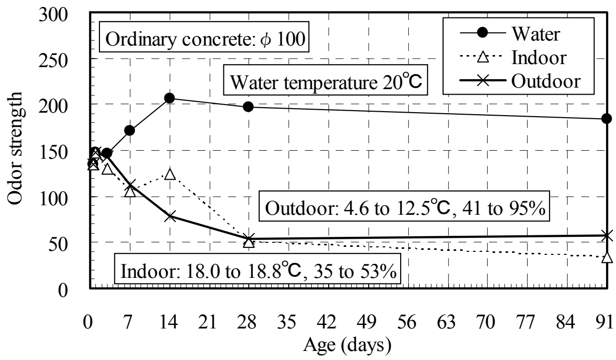

Figure 3.4 Relationship between odor strength of ordinary concrete for each curing condition and ages

concrete specimen for each curing condition. The internal temperature and humidity at a start are initial concrete temperature and 100% of internal humidity. The temperature of the concrete was 16 to 20℃ in water and indoor curing conditions and it was almost the same as the curing temperature. However, the temperature of both concretes has once risen at the age of 7 days in case of outdoor atmospheric curing. It has fallen after the age of 14 days with the progression of ages, and it was almost the same as the outdoor atmospheric temperature 0℃ at the age of 91 days. The effect of the difference of diameter of the specimen on the temperature could not be observed. The humidity in the concrete specimen was 96 to 99% in the standard curing irrespective of the diameter. However, it lowered with the progression of age in indoor and outdoor atmospheric curing. The humidity in indoor atmospheric curing was much lower than that in outdoor one. The degree of lowering is depend on the size of diameter. At the age of 91 days, the humidity in the specimen with the 75mm diameter was reduced to 24% and 14% from the humidity in the specimen with the 150mm diameter in the indoor and outdoor atmospheric curing which was sheltered from the rain. This fact was caused by easy evaporation of free water from the specimen with small size of diameter.

As mentioned above, it shows that the fluctuation of the temperature and humidity in the curing condition and the difference of member size control the curing effect. It is important to develop the method to evaluate the curing effect easily from the viewpoint of the quality assurance of concrete structure.

3.2 Measurement results of odor strength in concrete specimen

It is generally known that the calcium hydroxide is crystallized with the progress of hydration reaction of the cement in concrete and the amount of crystallization of calcium hydroxide increases for curing [3]. It has been considered that the curing effect can be measured by a simple evaluation of the amount of calcium hydroxide. It was examined whether the odor strength as an index to evaluate the curing effect was appropriate or not in this section.

Figure 3.4 shows the relationship between odor strength of ordinary concrete for each curing condition and ages as an example. The odor strength in case of the standard curing tends to increase initially and approach to a constant value with an increase in age. The odor strength in case of indoor and outdoor atmospheric curing decreases with an increase in the age. In these cases, the differences

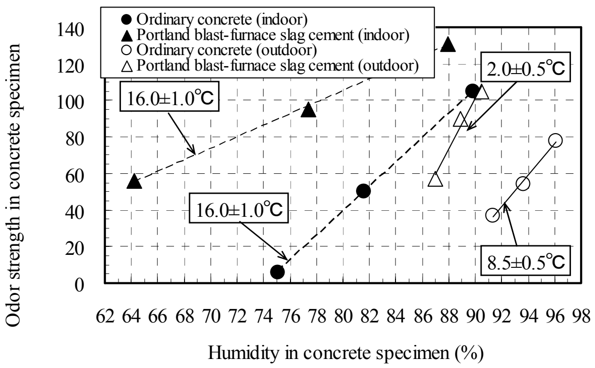

Figure 3.5 Relationship between humidity and odor strength in concrete specimen

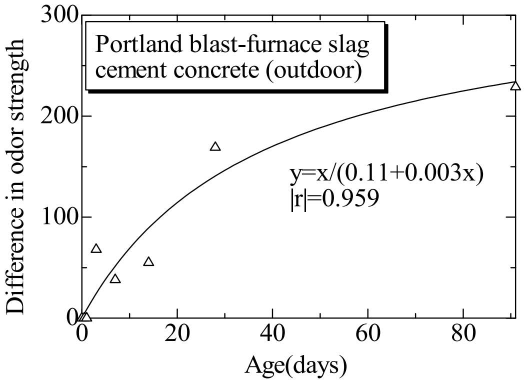

Figure 3.6 The age dependent change of the difference in odor strength of concrete in case of portland blast-furnace slag cement concrete

between odor strength in standard curing and indoor atmospheric curing, and outdoor atmospheric curing at the ages of 91 days were 82 and 69% of the odor strength in case of the standard curing. It is considered that these results were caused by the delay of hydration reaction of concrete due to the drying environment in indoor atmospheric curing and drying and low-temperature environment in outdoor atmospheric curing.

The relationships between odor strength and temperature, and humidity were examined since the curing effect depends on the temperature and humidity in concrete as shown in 3.1. Figure 3.5 shows the relationship between humidity and odor strength for a given temperature in N and BB concrete specimen. The odor strength increases with an increase in the humidity in concrete specimen for a given temperature. And, the odor strength increases with an increase in the temperature in concrete specimen for a given humidity. From these results, it is considered that the odor strength in the concrete is related to the change in the temperature and humidity which greatly influences on the curing effect. The odor strength in portland blast-furnace slag cement concrete BB is higher than that in ordinary concrete N for a given humidity at 16±1℃. This fact is probably due to the odor characteristic of the blast-furnace slag powder contained the slag cement.

3.3 Evaluation of curing effect of blast-furnace slag cement concrete by measuring difference of odor strength

The difference between odor strength in the standard curing and that in each curing condition was defined as the difference in odor strength, and the change of the difference with the age was examined. Figure 3.6 shows the age dependent change of the difference in odor strength of concrete in case of portland blast-furnace slag cement concrete BB as an example. The difference in odor strength increases with the age, and the value of portland blast-furnace slag cement concrete is 229 and 252 at the age of 91 days in outdoor and indoor atmospheric curing. The values of ordinary concrete were 150 and 126 at the age of 91 days in indoor and outdoor atmospheric curing conditions. The smaller the difference in odor strength is, the closer the curing condition is to standard curing. Therefore, it is judged that indoor and outdoor atmospheric curing for portland blast-furnace slag cement concrete were sever rather than those for ordinary concrete. And, it was clarified that the time dependent curve of this difference in odor strength could be closely approximated by a hyperbolic function for each

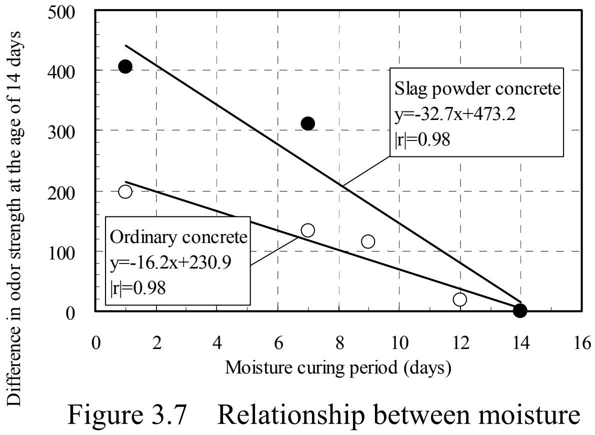

Figure 3.7 Relationship between moisture curing period and difference in odor strength at the age of 14 days

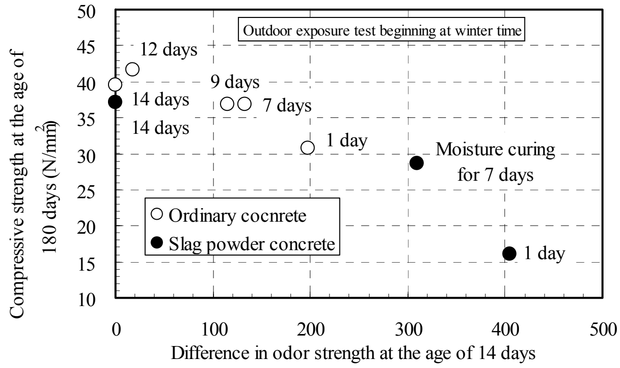

Figure 3.8 Relationship between difference in odor strength at the age of 14 days and compressive strength at the age of 180 days in outdoor exposure test

concrete type and curing condition.

In order to evaluate the curing effect of the concrete using blast-furnace slag powder by odor strength, the specimens of ordinary concrete N and slag powder concrete BP cured in moisture condition (standard curing) during different period were exposed in outdoor atmosphere in winter season. 50% of normal portland cement was replaced by the slag powder with 6000 cm^2/g of specific surface area. The difference in odor strength of the specimen was measured at the age of 14 days.

Figure 3.7 shows the relationship between moisture curing period and the difference in odor strength of the specimen in outdoor atmosphere at the age of 14 days in winter time. The difference in odor strength decreases with an increase in the period of moisture curing. As shown in this figure, it is necessary to prolong the moisture curing period for slag powder concrete compared with ordinary concrete to obtain a given difference in odor strength in winter time. It is generally accepted that an increase in the period of moisture curing produces curing effect. It therefore is considered that the decrease in the difference in the odor strength with an increase in the period of moisture curing evaluates the curing effect of the slag powder concrete.

Finally, the effect of the curing effect on the quality such as long term compressive strength (180 days) was examined. Figure 3.8 shows the relationship between difference in odor strength at the age of 14 days and compressive strength at the age of 180 days in outdoor exposure test beginning at winter time. The numerical values in the figure show water curing period before starting the outdoor exposure test. The compressive strength at the age of 180 days in outdoor exposure test decreases with an increase in difference in odor strength at the age of 14 days.

From these results, it is considered that the level of the difference in odor strength measured at initial age assures the quality such as long term strength of slag powder concrete cured in different condition.

4. CONCLUSIONS

An evaluation of curing effect of ordinary concrete N and portland blast-furnace slag cement concrete BB in standard curing, indoor and outdoor atmospheric curing condition was examined by measuring compressive strength, temperature and humidity in concrete specimen, and odor strength in concrete specimen by using odor sensor. The slag powder concrete BP cured in moisture condition (standard curing) during different period was exposed in outdoor atmosphere in winter season, and the curing effect evaluated by the difference in odor strength was compared with ordinary concrete N. The following results were obtained.

The fluctuation of temperature and humidity in the curing condition and the difference of member size control the curing effect.

It was judged that the measurement of the odor strength in the concrete could evaluate the difference of the amount of the calcium hydroxide formed by the difference in progression of hydration reaction due to different curing condition.

The odor strength in the concrete N and BB was related to the change in the temperature and humidity which greatly influenced on the curing effect.

The difference between odor strength in the standard curing and that in each curing condition was defined as the difference in odor strength. The difference in odor strength of slag powder concrete BP decreased with an increase in the moisture curing period before exposing in outdoor atmosphere.

It was necessary to prolong the moisture curing period for slag powder concrete BP compared with ordinary concrete N to obtain a given difference in odor strength in winter time.

The level of the difference in odor strength measured at initial age assured long term strength of slag powder concrete cured in different condition.

REFERENCES

[1] Iyoda, T. and Uomoto, T. : Progress of hydration and amount of free water in hardened cement in arid condition continuously on early curing, *Cement Science and Concrete Technology*, No.54, pp.167-173, (2000).

[2] Shirokado, Y., Chang, D. and Kagaya, M. : Evaluation of curing effect of fly ash cement concrete by using odor sensor, *Proceedings of the Japan Concrete Institute*, Vol.30, No.2, pp.217-221, (2008).

[3] Yamada, J. and Ariizumi, M. : Knowledges on cement and concrete properties for beginners, *Kajima Publication Association*, pp.80-81, (1982)